The effect of a weight reduction program
on measures of protein and fat resources

An Honors Thesis (ID 499)

by

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INTRODUCTION

A preoccupation with weight loss in American society has become epidemic in the past decade. This is a result of a growing awareness of improved health and longevity through fitness and proper nutrition. Results of this awareness are noted in the decreased mortality due to coronary heart disease (1).

Accompanying the trend toward thinness is the desire to achieve this state through a minimal amount of effort and time. This attitude has alerted professionals in the health care field to many gimmicks and fads which make unreasonable guarantees or which have been associated with particular physiological risks. One major concern is that as a result of rapid weight loss and inadequate energy intake lean body tissue, which is made up of those components other than fat, will be compromised as a source of energy.

Muscle tissue comprises approximately forty percent of the total body weight in an adult male. It is primarily water, although the protein portion of the tissue is non-aqueous. During extreme and rapid weight loss, the fat and protein stores of the body are utilized for energy causing several alterations of bodily functions (2).

At the histological level, there is an increase in connective tissue, enlargement of the extra cellular space, diminished myofiber mass, increased muscle water, and decreased cellular protein levels (2). When available fat stores are exhausted or when energy needs exceed the rate of efficient fat catabolism in the absence of sufficient carbohydrate intake, the cellular proteins become the principle endogenous source of energy for the body (3). Therefore, muscle protein is catabolized and oxidized, eventually leading to atrophy (2). This breakdown provides amino acids for gluconeogenesis and protein synthesis in the liver (4).

There are several other physiological changes associated with prolonged semi-starvation. Body temperature decreases as well as the rate of chemical reactions, concentrations of enzymes, and their substrates (3). Blood glucose levels also drop, and the organism's capacity for work diminishes (3).

These changes explain the tendency after an extended period of negative calorie balance for body weight to reach a steady state at which point caloric expenditure tends to balance caloric intake (5). Even during complete starvation efficiency of weight reduction is lost, and cannot be recommended as a method of weight loss (5).

The decrease in the Basal Metabolic Rate (BMR) is responsible for balancing the caloric output with the caloric intake and sparing the body's protein reserves (5). A lowered BMR leads to poor motivation, loss of cardiovascular capacity, loss of muscular strength, and poor capacity for anaerobic work (5). In a study conducted by Keys, it was noted that subjects placed on a 400-600 cal/day diet experienced a drop in BMRs at a rate faster than a drop in weights (5).

It has been suggested that while the body is in a state of negative calorie balance a slow rate of weight reduction and adequate protein intake in conjunction with exercise are factors which contribute to the preservation of lean body tissue while the body is in a state of negative calorie balance (5).

Zuti and Golding compared the effects of diet, exercise, and the combination of the two on body composition of adult women undergoing weight reduction (6). Three groups were placed on different regimens. Group one achieved negative calorie balance through decreased caloric intake only, while group two achieved the same status with a combination of reduced caloric intake plus exercise, and group three through exercise alone. The method of weight reduction did not significantly affect the amount of mass lost, but there were notable differences in body composition. Body density increased in all groups which indicated either an increase in muscle mass or a decrease in fat mass or both. The higher the level of intensity of exercise, the higher the increase in body density. Persons in the diet only group lost greater amounts of lean tissue than the other two groups. Those subjects in the groups which exercised actually increased lean tissue mass. This was attributed to an increase in already existing muscle fibers associated with an increase in myofibrose and sarcoplasmic proteins. The diminished lean tissue mass noted in subjects from group one was attributed to excess protein loss or inadequate replacement of protein through diet leading to the undesireable state in which muscle protein is catabolized for energy (6).

At one time there was a common belief among athletes that a strain on the muscles could be compensated for through increased protein consumption (3). Today this is considered to be a misconception because increased physical work does not increase protein catabolism significantly if the diet is calorically adequate (3). It is true that physical work does increase caloric need which indirectly increases protein need as well.

During a prolonged period of weight reduction as one means of sparing muscle protein, it is recommended that 1 gm protein per kg body weight (BW) be incorporated into the daily diet (2).

Several methods are utilized in the assessment of lean body tissue, and more specifically protein status, of an individual at risk for protein energy malnutrition (PEM) or in a state of prolonged weight reduction. The two most common techniques employed are the biochemical and anthropometric determinations and analyses.

Each of these methods have the capacity to assess body protein status. Biochemical determination involves such measurements as serum albumin, transferrin, muscle glycogen, urea nitrogen levels, as well as collagenous and non-collagenous protein fractions (2). These measurements are primarily used to indicate changes in visceral protein status (7).

Anthropometric tools and measurements are used to identify changes in muscle or somatic protein status and are often used to determine the need for further biochemical investigation. Measurements most often taken include height, weight, body circumferences and skinfolds. The advantages of anthropometry in assessing nutritional status are the minimum amount of equipment, effort, time, and expense required (7) as well as the fact that there is no invasion of the skin, eliminating any risk of infection (8). Once these measurements are taken, inferences can be made as to the nutritional status of an individual by comparing the obtained values with a table of standards.

The most accurate method of evaluating percent body fat is through hydrostatic weighing. It is possible to employ other techniques if elaborate equipment is not available. These techniques include measuring body circumferences, skinfolds, and often a combination of both. Lean body weight is then determined by subtracting the fat weight from the total body weight.

Mid upper arm area, muscle area, muscle circumference, and fat area can be determined from the triceps skinfold and the mid upper arm circumference (7). It is an unproven assumption that both in good health and in PEM the size of the muscle bears an unknown but constant relationship to muscle composition and specifically muscle protein and energy content (2).

The triceps skinfold is considered to be the best index of the subcutaneous fat stores of the body while the upper arm muscle circumference is considered to be the best index of the body's muscle protein reserve (10). The upper arm muscle circumference (AMC) is determined using the following equation:

$$AMC = MAC - (\pi \times TSF)$$

where MAC = upper mid arm circumference and

TSF = triceps skinfold (9).

The upper arm is used because it is relatively free of edema thus rendering more accurate measurements (10). In the determination of mid upper arm area (MAA), the following equation is used:

$$MAA = MAC^2/4\pi \text{ (9).}$$

Arm muscle area (AMA) is determined as follows:

$$AMA = (MAC - \pi \times TSF)^2/4 \quad \text{(9).}$$

Fat area (FA) can then be determined by subtracting the arm muscle area from the total arm area:

$$FA = MAA - AMA \text{ (9).}$$

Fat areas are useful in estimating absolute total body fat or fat weight but not relative total body fat or percent body fat (2). Fat weight is a more useful variable than percent body fat because the relationship between skinfolds and fat weight is more linear than the relationship between skinfolds and percent body fat (12). There is also evidence that fat areas are systemically better estimates of weight and energy reserves than skinfold thicknesses (12). There are several sources of error in the measurement of upperarm muscle area as well as in the calculations. Therefore this measure can only be considered approximate because 1) the muscle circumference does not include an estimate of body diameter, and variation in humeral diameter is not accountable; 2) the equations assume that the upper arm is cylindrical and that there is an even distribution of fat. Flattening of the arm is more prevelant in males than in females causing an overestimation of male muscle area; 3) the variation in compressibility of the skinfold which leads to an underestimation of female muscle for which the reason in unclear (4).

Both triceps skinfold and arm circumference underestimate the magnitude of the tissue changes in the upper arm (7). It takes more fat to cover a larger limb with a given thickness of subcutaneous fat than it does to cover a smaller limb with comparable thickness (12). An individual may also increase underlying muscle and bone while retaining the same fatness, but the subcutaneous thickness would decrease proportionally, not because of decreased fatness, but because of increased muscle circumference (12).

Despite the aforementioned disadvantages of using anthropometry, these techniques are the most reliable sources available for the assessment of the muscle protein and fat mass status of an individual. Therefore, when caution is exercised while engaging in anthropometric methods, these tools are invaluable in the determination and analysis of nutritional status.

This study was designed to assess, through the use of anthropometry, the changes in the muscle protein status of subjects participating in an extended weight reduction program. It was also a goal of the author to determine the effect of protein intake, exercise, and the rate of weight loss on muscle protein status.

MATERIALS AND METHODS

Subjects who participated in this study were clients at a university based weight management clinic for adults. Seven individuals originally consented to participate in the 16 week study, and the final group consisted of three females and one male.

Anthropometric measurements were done at three separate 5 week intervals during a 16 week period. The measurements used in the assessment were height (cm) and weight (kg) in stocking feet, mid upper arm circumference (mm)*, and triceps skinfold (mm) **.

Mid upper arm circumference was measured at the halfway point between the tips of the acromion and olecranon processes of the right arm with the arm pendant (9). The triceps skinfold measurements were taken in duplicate at this point and the average value recorded (9). These values were plugged into the previously cited equations, and mid upper arm area, arm muscle area, arm muscle circumference, and upper arm fat area values were derived (9).

Each subject was placed on modest caloric restriction, based on The American Diabetes Association (ADA) Exchange System, designed to help achieve a weight loss at the rate of approximately one to two pounds per week. The diets were individually calculated assuming a caloric expenditure through exercise of 800 kcal per week for the females and 1200 kcal per week for the males, of 114 kcal and 172 kcal per day respectively. When

* using a Ross Laboratory Ensure Insertape
** using a Lange Caliper which exerts $10 mg/mm^2$ pressure on the contact surface (9).

reasonable, care was taken to insure that each subject was assigned a protein intake of approximately 1 gm per kg of original body weight.

RESULTS AND DISCUSSION

The age, height, and changes in body weight are shown in TABLE 1. All subjects lost a minimum of 4.2 kg with an average loss of 5.83 kg for the females and 6.92 kg for all subjects. The percent of decrease in body weight among the female subjects was similar as reflected by a range of 7.0 to 8.0% and average of 7.3%. The male subject lost 11.9% of his original body weight boosting the overall average to 8.5%. The rate of weight loss for the 16 week period ranged from .263 kg/week to .638 kg/week. Converting these values to pounds reveals that the rate of weight reduction is closely associated with the prescribed reduction of one to two pounds per week and suggests a high level of adherence to the prescribed caloric intake shown in TABLE 2.

It should be noted that each subject was indeed placed on a diet which provided approximately 1 gm protein per kg body weight. As body weight decreased, predictably, the protein intake per kg body weight increased proportionally during each 5 week interval. The greatest increase in protein intake per unit body weight occurred in subject #4 who lost the greatest body mass. The result of this theoretically adequate protein intake may be reflected in a diminished loss of muscle protein during weight reduction.

Changes in mid upper arm circumference (MAC) and triceps skinfold (TSF) measurements are shown in TABLE 3. All subjects decreased their MAC by at leat 15 mm. The average loss for the females was 19.0 mm and for all the subjects was 18.0 mm. The percent decrease in MAC among all subjects was similar with an overall average decrease of 5.2%.

Compared to the age and sex specific standards compiled by Bishop (8), MAC values for subject #1, trial #1, fell above the 95th percentile and reduced just to the 95th percentile mark when trial #3 was done. Mac values for subject #2, trial #1, fell exactly at the 25th percential and decreased to a point between the 10th and 25th percentile by trial #3. MAC values for subject #3 fell between the 59th and the 75th percentile for trial #1 and decreased to a point between the 25th and 50th percentile for trial #3. Subject #4 had a MAC for trial #1 which fell between the 75th and the 90th percentile, and by the time trial #3 was taken, he had decreased to a percentile just at the 75th mark.

All subjects decreased their triceps skinfolds (TABLE 3). The decreases ranged from 1.0 mm to 9.0 mm. The average decrease for the females was 5.2 mm and 5.1 mm overall. The wide range of change was magnified in the percent of change in TSF values, however, the average decrease for the group was nearly 25%. Subject #1 experienced a 5.0% decrease while subjects #2 and #4 experienced a 36% and a 33% decrease respectively. According to Bishop's standards, TSF for subject #1, trial #1, fell between the 25th and the 50th percentile, slightly increased in trial #2, and decreased to nearly the 25th percentile mark in trial #3. Subject #2 remained stable for trial #1 and #2 precisely at the 50th percentile then took a dramatic decrease in trial #3 falling to just above the 10th percentile. Subject #3 made a steady decrease from the midpoint between the 25th and the 50th percentile at trial #1 to a point between the 10th and the 25th percential at trial #3. Subject #4, trial #1, displayed a TSF measurement which fell at the 75th percentile and decreased to nearly the 25th percentile mark at trial #3.

Changes in upper mid arm area (MAA), arm muscle area (AMA), and arm muscle circumference (AMC) over the 16 week period are shown in TABLE 4. All subjects decreased in MAA with an average percent decrease for the female subjects of 10.6% and 10.1% overall.

The AMA and AMC evaluations were interesting as subject #1 decreased in MAA while subjects #2 and #3 experienced increased MAA, and subject #4 showed no significant change.

Compared to the Health Examination Survey Standards (6), for MAA, subject #1 was well above the 95th percentile when she began the study and maintained that level after experiencing the decrease in MAA. Predictably, subject #1 also remained above the 95th percentile for AMC.

Subject #2 exhibited a noteworthy increase in AMA and AMC. At the beginning of the study, her AMA fell almost to the 50th percentile and by trial #3 had increased to the midpoint between the 50th and the 75th percentile. Her increase in AMC followed a similar path.

Subject #3 also experienced a slight increase in upper arm muscle. The values for all trials consistently fell above the 95th percentile. Subject #4 showed no significant change in either AMA or AMC, and the values consistently stayed between the 25th and 50th percentiles according to the standards for adult men.

As predicted, all subjects decreased in mid upper arm fat area (FA) (TABLE 5). The losses varied greatly among subjects, ranging from 369 mm^2 to 1204 mm^2. The average decrease for the females was 831 mm^2, and the average for all subjects was 824 mm^2. The average percent decrease was 24.3% for the females and 26.2% overall. Percent changes in FA were similar to percent changes in TSF, but fat area measures are more reflective of change in total fat mass (12).

From these results, several facts can be summarized; 1) all subjects experienced a slow and consistent rate of weight reduction; 2) all subjects were advised to consume at least 1 gm protein per kg body weight in conjunction with a regular exercise program in order to diminish muscle protein catabolism; 3) Mid upper arm circumference and triceps skinfold measurements consistently decreased with decreases in body weights; 4) Mid upper arm area decreased as mid upper arm circumference and triceps skinfold measurements decreased; 5) subject #2 experienced a significant increase in both arm muscle area and arm muscle circumference while subjects #3 and #4 experienced only a negligible change, and subject #1 decreased her overall upper arm muscle protein status; 6) In all subjects, fat area decreased with a decrease in upper arm area and an increase in arm muscle area and circumference.

These results are consistent with the findings of Zuti and Golding (6). The percent weight lost was fairly uniform among the subjects reinforcing the credibility of and the overall adherence to the prescribed diet. Assuming that each subject consumed the advisable amount of protein, there should have been a minimal amount of catabolism of protein for energy. The actual level of exercise was not monitored, therefore, only a theoretical conclusion backed by literature was drawn regarding the effect of exercise on muscle protein status during weight reduction.

The changes in mid upper arm circumference and triceps skinfold measurements followed a predictable pattern of decrease. Mid upper arm area is contingent upon the mid upper arm circumference and triceps skinfold, therefore a decrease was observed.

An increase or negligible change in the mid upper arm muscle area of subject #2, #3, and #4 suggests that exercise must play a role in muscle preservation during weight loss. The muscle area decrease experienced by subject #1 coincides with the data obtained for the non-exercise group in the study conducted by Zuti and Golding (6).

Whenever a reduction of body weight is experienced, a reduction of fat weight also occurs. This fact was exemplified by the consistent decrease in the mid upper arm fat area in each of the four subjects.

In order to prove that the level of exercise and the protein intake have a significant effect on muscle protein status during weight reduction, further research must be done involving a control group compared to an experimental group. Conclusions derived prior to this research are considered to be hypothetical.

At the end of the 16 week period, all four subjects appeared to be in good health and showed no clinical signs, anthropometric or otherwise, of protein energy depletion. In conclusion, it is reasonable to state that adequate protein and caloric intake, exercise, and a slow rate of weight loss contribute to the preservation of muscle protein during weight reduction. Through the use of anthropometric techniques in conjunction with available equations, an extremely reliable method of assessing changes in muscle protein status can be established to closely monitor the overall nutritional status of the individual.

TABLE 1. Age, height, change in weight and average rate of weight loss during a 16 week weight reduction program

subjects	age(yrs)	height(cm)	weight(kg) 1	weight(kg) 2	weight(kg) 3	weight(kg)	%Δ	$\bar{X}$ (kg body wt/week)
females								
1	65	170.8	96.4	92.3	89.5	-6.8	-7.0	-.425
2	50	157.7	60.0	56.6	55.8	-4.2	-7.0	-.263
3	48	170.2	81.6	78.6	75.1	-6.5	-8.0	-.406
$\bar{X}$ females	54.3	166.2	79.3	75.8	73.5	-5.8	-7.3	-.365
male								
4	56	173.0	85.5	79.8	75.3	-10.2	-11.9	-.638
$\bar{X}$ all subjects	54.8	167.9	80.9	76.8	73.9	-6.9	-8.5	-.433

TABLE 2. Weight reduction prescriptions: kcal and protein intake

subjects	kcal/day	Prot(g)/day	Prot(g)/kg body weight			Exercise
females			1	2	3	miles/day
1	1485	94	0.98	1.02	1.05	1.14
2	1440	73	1.22	1.30	1.31	1.14
3	1665	96	1.20	1.22	1.28	1.14
$\bar{X}$ females	1530	87.7	1.12	1.18	1.21	1.14
male						
4	1955	91	1.06	1.14	1.21	1.7
$\bar{X}$ all subjects	1636	88.5	1.11	1.17	1.21	1.28

TABLE 3. Changes in upper mid arm circumference (MAC) and triceps skinfold (TSF) in subjects during weight reduction

subjects	MAC(mm)			MAC(mm)	%Δ	TSF(mm)			TSF(mm)	%Δ
females	1	2	3			1	2	3		
1	381	368	359	-22.0	-5.8	20.0	21.5	19.0	-1.0	-5.0
2	300	285	282	-18.0	-6.0	25.0	25.0	16.0	-9.0	-36.0
3	347	338	331	-16.0	-4.6	22.5	20.5	17.0	-5.5	-24.4
$\bar{X}$ females	343	330	324	-19.0	-5.5	22.5	22.3	17.3	-5.2	-23.1
male										
4	346	339	331	-15.0	-4.3	14.25	13.5	9.5	-4.75	-33.3
$\bar{X}$ all subjects	344	332	326	-18.0	-5.2	20.4	20.1	15.4	-5.06	-24.8

TABLE 4. Changes in upper arm area (MAA), muscle area(AMA), and muscle circumference (AMC) in subjects during weight reduction

subjects	MAA(mm^2)			MAA	% Δ	AMA(mm^2)			AMA	%Δ	AMC(mm)			AMC	%Δ
females	1	2	3			1	2	3			1	2	3		
1	11547	10772	10252	-1295	-11.2	8051	7180	7125	-926	-11.5	318	300	299	-18.9	-5.9
2	7159	6461	6326	-833	-11.6	3900	3390	4271	+371	+9.5	221	206	232	+10.3	+4.7
3	9578	9061	8715	-862	-9.0	6072	5932	6129	+57	+.94	276	273	278	+1.28	+0.46
$\bar{X}$ females	9428	8765	8431	-977	-10.6	6008	5500	5842	-166	-2.8	272	260	270	-2.43	-0.89
male															
4	9523	9141	8715	-808	-8.5	7217	6996	7214	-3.42	-.05	301	297	301	+.07	-0.02
$\bar{X}$ all subjects	9452	8859	8502	-950	-10.1	6310	5874	6185	-126	-2.0	279	269	277	-1.81	-0.65

TABLE 5. Changes in fat area (FA) in subjects during weight reduction

subjects females	FA(mm^2) 1	2	3	FA(mm^2)	%Δ
1	3496	3593	3127	-369	-10.6
2	3259	3071	2055	-1204	-36.9
3	3505	3129	2586	-920	-26.2
$\bar{X}$ females	3420	3264	2589	-831	-24.3
male					
4	2306	2145	1501	-804	-34.9
$\bar{X}$ all subjects	3142	2985	2317	-824	-26.2

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